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(54) Metal foil with improved bonding to substrates and method for making said foil.

(57) A metallic foil with improved bonding to substrates is disclosed which has on a surface thereof three superimposed electrodeposited layers, the first layer adjacent to said surface comprising a dendritic deposit comprising a major amount of a first metal, the second layer comprising a metal flash uniformly deposited over said first layer comprising a major amount of a second metal other than said first metal, and a third layer comprising a dendritic deposit comprising a major amount of a metal other than said first metal. A method for making such foil is disclosed which comprises (A) electrodepositing a dendritic deposit comprising a major amount of a first metal on one surface of said foil; (B) electrodepositing over the dendritic deposit of (A) a metal flash comprising a major amount of a second metal other than said first metal of (A); and (C) electrodepositing on said metal flash of (B) a dendritic deposit of a metal layer comprising a major amount of a metal other than said first metal of (A). The improved foil is useful for a wide range of applications that benefit from the improved bonding to substrates, including electronic devices such as printed circuit boards and solid state switches.

EP 0 525 956 A2

This invention relates to treatment of electro-deposited metal foils used particularly, but not exclusively, to make electronic devices and a process for making such foils. In particular, the present invention relates to metal foil surface treatment processes for improving adhesion between metal foils and substrates and reduced treatment transfer to substrate. In connection with laminated electronic devices such as printed circuit boards, the substrate may be a laminating material.

Metal foil, such as copper foil, has become widely used in a wide variety of electronic and electrical component technologies. A separate field of technology has developed for the production of metal foils useful in such industries to achieve properties useful for various applications. Commercially, the primary means by which desirable properties are added to metal foil is by electrodeposition of metals from metallic ion-containing baths. Such processes have been used to produce a matte surface having microscopic dendritic (i.e., tree-like or nodular) structures to aid in adhering the foil surface to other materials. Electrodeposition has also been used to apply certain metals as a thermal barrier, an elevated temperature metal diffusion barrier, an oxidation barrier, a chemical corrosion barrier, and/or provide certain electrical properties such as electric current resistance.

After it has been treated to achieve the aforementioned properties, metal foils, such as copper, tin and nickel foils, are particularly well suited for use in various electronic and electrical components. Of particular interest are printed circuit boards (PCBs) and PCB components, especially multilayer PCB laminates, solid state switches and the like which have been developed to meet the demand for miniaturization of electronic components and the need for PCBs having a high density of electrical connections and circuitry. The technologies for the production of such foils by electrodeposition from electroplating baths and/or by processing the metal in a roll mill are well known in the art.

A typical example of production of a metal foil for electronic applications is the production of copper foil by electrodeposition processes. Such processes generally involve the use of an electroforming cell (EFC) consisting of an anode and a cathode, an electrolyte bath solution, generally containing copper sulfate and sulfuric acid, and a source of current at a suitable potential. When voltage is applied between the anode and cathode, copper deposits on the cathode surface.

The copper foil making process begins by forming the electrolyte solution, generally by dissolving (or digesting) a metallic copper feed stock in sulfuric acid. After the copper is dissolved the solution is subjected to an intensive purification process to ensure that the electrodeposited foil contains no disruptions and/or discontinuities. Various agents for controlling the properties may be added to the solution.

The solution is pumped into the EFC and when voltage is applied between the anode and cathode, electrodeposition of copper occurs at the cathode. Typically, the process involves the use of rotatable cylindrical cathodes (drums) that may be of various diameters and widths. The electrodeposited foil is then removed from the cylindrical cathode as a continuous web as the cathode rotates. The anodes typically are configured to conform to the shape of the cathode so that the separation or gap therebetween is constant. This is desirable in order to produce a foil having a consistent thickness across the web. Copper foils prepared using such electrodeposition methodology have a smooth shiny (drum) side and a rough or matte (copper deposit growth front) side.

Conductive foils for PCB applications and other electronic devices may be treated, at least on the matte side, for enhanced bonding and peel strength between the matte side and the laminate. Typically the foil treatment involves treatment with a bonding material to increase surface area and thus enhance bonding and increase peel strength. The foil may also be treated to provide a thermal barrier, which may be brass, to prevent peel strength from decreasing with temperature. Finally, the foil may be treated with a stabilizer to prevent oxidation of the foil.

A problem which accompanies treating the matte side of a conductive foil with a different metal is that the treatment can result in poor adhesion and inadequate resistance to thermal and mechanical stress. The poor results may be measured as low or inadequate peel strength values and/or may be observed as a separation of the electrodeposited foil treatment from the foil, known as "board transfer" or "treatment transfer". The present invention provides a procedure for obtaining metal foil having improved peel strength and reduced treatment transfer.

One aspect of the present invention is a metallic foil having on a surface thereof three superimposed electrodeposited layers, the first layer adjacent to said surface comprising a dendritic deposit comprising a major amount of a first metal, the second layer comprising a metal flash uniformly deposited over said first layer comprising a major amount of a second metal other than said first metal, and a third layer comprising a dendritic deposit comprising a major amount of a metal other than said first metal.

In another aspect of the present invention, the present invention is a process for making metal foil capable of improved bonding between the foil and a substrate comprising:

(A) electrodepositing a dendritic deposit comprising a major amount of a first metal on one surface of

said foil;

(B) electrodepositing over the dendritic deposit of (A) a metal flash comprising a major amount of a second metal other than said first metal of (A); and

(C) electrodepositing on said metal flash of (B) a dendritic deposit of a metal layer comprising a major amount of a metal other than said first metal of (A).

Another aspect of the present invention is producing an electronic device from the metallic foil of the present invention. Included as electronic devices are devices comprising a laminated metallic foil of the present invention, such as the PCBs described above, and solid state switches, including solid state circuit breakers.

Various preferred features and embodiments of the present invention will now be described by way of non-limiting example with reference to the accompanying drawings, in which:

Figure 1 is a photomicrograph showing a 1000 X magnification of a cross-section of copper foil having an upper matte side and a lower smooth side, which is coated with a nickel flash in accordance with step (B) of one embodiment of the process of the present invention.

Figure 2 is a photomicrograph showing a 1000 X magnification of another cross-section of a copper foil having an upper matte side and a lower smooth side, which has been coated with a nickel flash in accordance with step (B) of one embodiment of the process of the present invention and then soaked in acid to etch away the copper under the nickel flash to more clearly show the contours of the nickel flash.

Figure 3 is photomicrograph showing a 1000 X magnification of a cross-section of copper foil treated with a nickel flash followed by a dendritic deposit of nickel in accordance with one embodiment of the present invention.

Figure 4 is a photomicrograph showing a 1000 X magnification of another cross-section of copper foil having an upper matte side and a lower smooth side treated with the nickel flash coating followed by a dendritic deposit of nickel on the matte side in accordance with one embodiment of the present invention, which was then etched with acid to dissolve away copper under the nickel treatments to show the contours of the nickel profile.

Figure 5 is a copy of three samples of transparent adhesive tape adhered to white paper, each outlined with a broken line to show each transparent adhesive tape outline, each sample having been previously adhered to a non-dusty, dusty and very dusty electrodeposited foil, respectively, as described in the legend over each.

For the purpose of the present invention, the term "dendritic" as used herein refers to microscopic metallic structures on a metallic surface which have a tree-like or nodular appearance. Methods for obtaining dendrites on a metallic foil are known in the art. Typically, dendrites can be obtained for most electrodepositable metals by conducting electrodeposition with a bath containing metal ions at a lower concentration and a substantially higher current density than that normally used to obtain a smooth electroplated finished product. Other conditions, such as pH, bath temperature and bath additives, can be used to further encourage the formation of dendritic deposits. U.S. Patent 3,328,275 and Bucci et al, "Copper Foil Technology", PC FAB (July 1986), pp. 22-31, each fully incorporated herein by reference, describe typical processes for producing dendritic deposits on copper foil.

Included as dendritic deposits are high profile, well as to low profile, dendritic deposits, and what the inventors identify as "dusty" or "very dusty" dendritic deposits. The "dusty" and "very dusty" dendritic deposits can be distinguished from non-dusty deposits by a simple standard qualitative test. An adhesive tape of the type known as Scotch brand™ (3M) transparent tape is firmly applied to the matte side, stripped off at a 90 degree angle and applied to a white sheet of paper. If hardly any trace of metal particles adhere to the tape, the deposit is considered non-dusty. If more than a trace appears on the tape, it is considered a "dusty" deposit. Figure 5 shows three adhesive tape samples corresponding to "non-dusty", "dusty" and "very dusty".

The term "metal flash" as used herein refers to a thin metallic electrodeposited coating having a low profile relative to the surface on which it is deposited. It is non-dendritic, as opposed to the dendritic surface described above. The metal flash is typically produced by utilizing electrodeposition conditions contrary to those required for dendritic deposits, namely high metal ion concentration in the electrodeposition bath and low current density relative to the concentration and current density used for dendritic deposits. Other factors, such as pH, bath temperature and bath additives, may be used to facilitate electrodeposition of a non-dendritic coating.

In the present invention, the metal flash is applied at a thickness which is less than the profile of the dendritic layer on which it is being deposited. Generally, the metal flash has an average cross-sectional thickness no greater than 20% of the average height of the dendrite from the metallic foil relative to the average depth of the valleys between dendrites (referred to hereinafter as the "average profile height"). The

average profile height may be determined based on photomicrographs such as those of Figures 1-4.

In a preferred embodiment, the average thickness of the metal flash is no greater than about 10% of average profile height. In one embodiment, the average thickness of the metal flash is not more than about 5% of the average profile height. The average thickness of the metal flash may be 10 microns or more. However for most applications, the average thickness is generally not be more than about 3.0 microns. In one embodiment, the average thickness may not be more than about 1.5 microns.

The thickness of the metal flash can be measured by conventional automated devices used in the metal foil plating industry and the average profile height can be determined from scanning electron microscope (SEM) photomicrographs of sample cross-sections such as those in Figs. 1 and 2. Once the appropriate electrodeposition conditions are determined, consistent results can be obtained.

To follow the contours of the dendrites, it is preferred that the metal flash have a fine grain structure relative to the grain structure of the dendritic layer below. Applying such a fine-grained coating generally facilitates application of a uniform metal flash.

The third layer of the foil of the present invention is an electrodeposited dendritic layer of metal. In a preferred embodiment, this layer comprises a major amount of the same metal which comprises a major amount of the metal flash below. This layer, again, is produced according to the well known procedures for making dendritic deposits described above in relation to the first dendritic layer. The specific electrodeposition conditions used to produce this dendritic layer will, however, often be somewhat different from that used to produce the first dendritic layer described above, because when different metals are electrodeposited, they often have their own concentration, pH, temperature and current density requirements for obtaining dendritic surface structure.

One of the more important factors in determining whether electrodeposition will result in non-dendritic or dendritic surface structure is current density. Typically, current density to produce non-dendritic surface structure will often be not more than about one-half the current density used to produce dendritic surface structure for the same metal being electrodeposited. In a preferred embodiment, the current density used to apply the metal flash is not more than about one-third of the current density used to produce a dendritic layer.

A nickel flash, for example, can typically be electrodeposited at a current density not more than about 300 amperes per square foot (ASF), and often at a current density not more than about 200 ASF. In one embodiment, a nickel flash is obtained by electrodeposition of nickel from a nickel electrodeposition bath at a current density of about 100 to about 150 ASF.

Another factor influencing whether electrodeposition results in non-dendritic or dendritic deposition is metal ion concentration in the electrodeposition bath. In general, the metal ion concentration in the bath used to apply the metal flash is at least twice that of the metal ion concentration used to apply a dendritic layer. In one embodiment, a nickel flash is obtained by electrodeposition of nickel from a nickel electrodeposition bath containing from about 85 to about 115 grams of nickel per liter of electrodeposition bath.

The pH and temperature conditions favorable toward non-dendritic or dendritic deposition vary from metal to metal. In the case of nickel, nickel flash deposition is often carried out in an aqueous bath having a pH up to 5.0 and at an elevated temperature of at least 30 °C. As a corollary, dendritic deposition to form the third layer is often conducted in an aqueous bath having a pH greater than 5.0 and a temperature less than 30 °C.

The time periods required for electrodeposition of the metal flash and the dendritic third layer vary depending on current density, metal ion concentration, pH, temperature and the particular metal being deposited. In one embodiment, a nickel flash may be electrodeposited from a nickel-containing bath over a time period in the range of from about 30 seconds to about 1 minute, and a dendritic nickel deposit as a third layer may generally be deposited over a time period in the range from about 10 to about 20 seconds.

A high profile dendritic metal deposit may generally be obtained when electrodeposition is conducted at a higher current density and a lower metal ion concentration than the current density and metal ion concentration used to obtain a corresponding low profile dendritic deposit. A similar approach may also be used to obtain a dusty dendritic metal deposit, but dustiness and average profile height are to be considered independently with respect to this invention. For example, a high profile deposit may be "dusty" or "nondusty". In the case of "dusty" high profile dendritic copper, the current density is generally in the range from about 250 to about 400 ASF, the copper ion concentration is in the range from about 24 to about 26 grams per liter of electrodeposition bath, and the bath temperature is generally in the range from about 90 °F to about 110 °F and the sulfuric acid concentration is in the range from about 90 to about 110 grams per liter of bath. Three to four grams of a nitrate per liter and about 22 to about 28 ppm chloride ion may be present to facilitate dusty copper deposition.

A wide variety of metals can be utilized in making the foil of the present invention. The metallic foil can

be made of any conductive metal. The first metal used to form the dendritic deposit on the metallic foil can also be selected from a wide variety of conductive metals capable of being electroplated. Typically, a metal is chosen which has good adhesion to the metallic foil upon electrodeposition under dendritic electrodeposition conditions. When the metallic foil is a copper foil, the first metal is generally copper, although zinc may also be used to form a dendritic zinc layer such as described in U.S. Patent 4,456,508, which is fully incorporated herein by reference.

The metals used as a metal flash in the second layer and/or as a dendrite-forming metal in the third layer include generally any metal which is capable of depositing according to the characteristics of a metal flash or dendritic third layer, respectively, as described above. Examples include nickel, tin, palladium, platinum, silver, gold and indium.

As mentioned above, the third layer generally comprises a major amount of a metal different from the major amount of metal in the dendritic first layer. Any metal which is capable of producing a dendritic deposit capable of adhering to the metal flash is within the scope of the present invention. Generally, the preferred major amount of metal in the third layer is the major amount of metal present in the metal flash.

Additional layers of electrodeposited metals may be included in the improved metal foil of the present invention. A layer of brass, for example, may be interposed between the dendritic first layer and the metal flash second layer to provide a thermal barrier. A thermal barrier is useful, for instance, to prevent peel strength from decreasing with increasing temperature when used in laminated printed circuit board applications involving high thermomechanical stress. Intermediate layers interposed between any dendritic layer and any subsequent layer should be deposited such that it does not substantially destroy the dendritic nature of the layer below, such as by filling the valleys between dendrites or bridging between the dendrite nodules.

As mentioned above, the metallic foils of the present invention can be used in a wide variety of applications which require a bondable conductive metallic foil. Typical applications include electrical and electronic applications in which a metallic foil is bonded to a substrate. Metallic foil laminates may be formed using the metallic foil of the present invention to form electronic devices, such as PCBs and solid state switches, capable of withstanding thermal and/or mechanical stress while maintaining good adhesion to the laminating material. In one embodiment, the average peel strength is at least about 12 lbs. per inch, often is at least about 13 lbs. per inch, and may be about 14 or more lbs. per inch.

There has been a need for conductive foils exhibiting improved peel strength and capable of enduring thermomechanical stress due to increasing reliance upon electronic components in harsh environments. Electronically controlled devices are becoming more common under the hoods of vehicles, such as cars, trucks, and heavy equipment, for microprocessor control of combustion conditions and in equipment used in industrial environments which subject the circuits to high temperatures and/or mechanical stress such as electronic chemical or metallurgical process control equipment, robotic equipment, etc. Stress may also be induced due to harsh geographical environments. Improved peel strengths and reduced treatment transfer are advantageous properties in the electronics field exhibited by the present invention, while additional valuable properties are obtained due to the presence of a major amount of at least one other metal on the metallic foil.

One embodiment which can be used to illustrate the present invention is a nickel treatment process on copper treatment. This process may be described as follows:

(1) Obtain a copper foil having a matte side obtained by electrodeposition of copper under conditions which form copper dendrites. The matte side cross-section may be either a low profile or high profile deposition. Greater benefit from the practice of this invention is often achieved with a high profile deposition as opposed to a low profile deposition;

(2) Optionally treat the matte side of the copper foil of step (1) with an intermediate electrodeposited metal layer, such as brass as a thermal barrier, provided that this intermediate layer does not substantially destroy the dendritic nature of the deposit on the matte side of the foil of step (1);

(3) Apply a nickel flash to this matte surface of step (1) or step (2). The metal flash layer seals the copper treatment and prepares the foil for step (3); and

(4) Electrodeposit additional nickel under electrodeposition conditions suitable for dendritic deposition.

Copper foil treated in the above manner is found to have higher peel strength and less treatment transfer than when the third step is applied directly to the matte side of the copper foil.

The following examples are provided for the purpose of illustrating the invention. Unless otherwise indicated, in the following examples, as well as throughout the specification and claims, all parts and percentages are by weight, all temperatures are in degrees Centigrade, all pressures are atmospheric, and process conditions are at standard pressure and temperature (i.e., at 25°C and 1 atmosphere).

Example 1

A copper foil having a smooth side and a matte side, the matte side having a standard non-dusty low profile electrodeposited dendritic copper deposit, is processed through two successive electrodeposition baths. The conditions of the first bath are as follows:

100 ± 15 grams per liter Ni
40 ± 5 grams per liter boric acid
4 ± 0.5 pH
110 ± 5° F
100-150 ASF current density

The term "ASF" refers to "amperes per square foot."

The conditions of the second bath are as follows:

25-30 grams per liter $NiCl_2$
65-75 grams per liter NH_4Cl_2
5.6-6.0 pH
63-67° F
600-750 ASF current density.

A cross-sectional view of copper foil after it has undergone electrodeposition in the first bath is shown in Figures 1 and 2. The copper foil appears as the lighter-shaded coarser-grained major portion of the cross-section material and the nickel flash appears as the slightly darker fine-grained material along the upper and lower contours of the copper foil material when looking at Figure 1. The upper portion with the rough profile is the matte side of the copper foil. Figure 2 shows a similar cross-section which has been etched by immersing the section in an acid bath to dissolve some of the copper. The resulting cross-section reveals the grain structure of the copper in the foil and the contours of the nickel flash along the copper. Dark areas between the copper foil and nickel flash are voids created by the acid etching copper from between the copper foil and nickel flash.

Figure 3 shows a cross-section of metal foil after it has been treated in the second bath. Again the copper is the lighter coarser-grained major portion of the cross-section material and the nickel appears again as the darker fine-grained areas along the upper profile. The photomicrograph clearly shows the formation of large nodular nickel dendrites along the upper profile of the treated foil.

Figure 4 shows a similar cross-section which has been treated with acid in the same way as the cross-section of Figure 2. The acid again created voids between the matte side of the copper foil and nickel, revealing the contours of the nickel on the foil side of the nickel electrodeposition. As can be seen, the nickel flash layer still closely follows the rough contours of the copper foil matte side.

Example 2

The copper foil of this example is treated in the same manner as that of Example 1, except that prior to processing the copper foil in the first bath, the matte side of the standard low profile copper foil is first treated with a brass electrodeposited coating to provide a thermal barrier. The results obtained after treatment with the first and second baths of Example 1 are otherwise closely analogous.

This example demonstrates that a copper foil can be treated according to the process of the present invention regardless of the presence of additional intermediate layers providing additional functional attributes.

Example 3

Copper foil is treated according to the process of Example 1, except the copper foil used in this example has a dusty high profile dendritic copper deposit on the matte side as determined by a standard qualitative tape adhesion test described above.

Example 4

Copper foil is treated according to the process of Example 2 using as the copper foil the dusty high profile foil of Example 3, which is first treated with a brass electrodeposited coating to provide a thermal barrier.

Each of Examples 1-4 (a) before nickel flash treatment, (b) after nickel flash treatment but before dendritic nickel treatment and (c) after dendritic nickel treatment according to the present invention were

tested for peel strength using a standard peel strength test. The standard peel strength test is based on GE-FR4™ lamination in which 4 inch by 1/2 inch samples are placed matte side down on one sheet of GE-16012™ prepreg, which is on top of three sheets of GE-16013™ prepreg, and then laminated at 350°F for 40 minutes at 1000 psi pressure. Peel strength is then measured at room temperature with a standard peel strength measuring device (Instron™), which measures the force required to pull the copper foil from the laminate at a 90 degree angle. The force required is expressed in pounds per inch (measured over a peel distance of at least one inch).

Nickel layer thickness may be measured using an Asoma Model 8620™ which measures nickel thickness by X-ray fluorescence.

The results obtained with the present invention compared with the results obtained with copper foil before nickel flash treatment and between nickel flash treatment and dendritic nickel treatment are shown in Table I below:

TABLE I

Peel Strength and Nickel Thickness Results			
Example No.	Treatment Stage	Average Peel Strength (lbs/inch)	Nickel Thickness in Microns on Matte Side
1	Before Ni flash After Ni flash Present invention	9.6 9.6 13.1	-- -- --
2	Before Ni flash After Ni flash Present invention	11.1 9.6 12.9	-- -- --
3	Before Ni flash After Ni flash Present invention	8.4 10.1 12.8	-- 1.1 2.2
4	Before Ni flash After Ni flash Present invention	10.3 11.6 13.5	-- 1.0 2.4

As can be seen from these results, the foil prepared according to the present invention has a higher peel strength than either the untreated dendritic copper foil or the dendritic copper foil with the nickel flash. The inventors have also observed reduced treatment transfer when practicing this invention.

While the invention has been explained in relation to its preferred embodiments, it is to be understood that various modifications thereof will become apparent to those skilled in the art upon reading the specification. Therefore, it is to be understood that the invention disclosed herein is intended to cover such modifications as fall within the scope of the appended claims.

Claims

1. A metallic foil having on a surface thereof three superimposed electrodeposited layers (a), (b) and (c) wherein:
   the first layer (a) adjacent to said surface comprises a dendritic deposit comprising a major amount of a first metal,
   the second layer (b) comprises a metal flash uniformly deposited over said first layer comprising a major amount of a second metal other than said first metal and
   the third layer (c) comprises a dendritic deposit comprising a major amount of a metal other than said first metal.

2. The foil of claim 1 wherein said third layer comprises a dendritic deposit comprising a major amount of said second metal.

3. The foil of either of claims 1 and 2 wherein said foil is a copper foil, said first metal is copper and said second metal is nickel.

4. The foil of either of claims 1 and 2 wherein said foil is a copper foil, said first metal is copper and said second metal is tin.

5. The foil of either of claims 1 and 2 wherein said foil is a copper foil, said first metal is copper and said second metal is palladium, platinum, silver, gold or indium.

6. The foil of either of claims 1 and 2 wherein the foil is a copper foil, said first metal is zinc and said second metal is nickel.

7. The foil of either claims 1 and 2 wherein the foil is a copper foil, said first metal is zinc and said second metal is tin.

8. The foil of either claims 1 and 2 wherein said foil is a copper foil, said first metal is zinc and said second metal is palladium, platinum, silver, gold or indium.

9. The foil of any preceding claim wherein the foil further comprises a layer of brass interposed between said first layer and said second layer.

10. The foil of any preceding claim wherein the average cross-section thickness of said second layer is not greater than about 10% of the average profile height of said first layer.

11. The foil of any preceding claim wherein said metal flash has an average thickness of not more than about 3.0 microns.

12. The foil of any preceding claim wherein the foil has a peel strength of at least about 12 lbs. per inch based on GE-FR4™ lamination.

13. An electronic device comprising at least one metallic foil according to any one of claims 1 to 12.

14. The device of claim 13, wherein the device is a printed circuit board.

15. The device of claim 13 wherein the device is a solid state switch.

16. A process for making a metallic foil comprising:
(A) electrodepositing a dendritic deposit comprising a major amount of a first metal on one surface of a metallic foil;
(B) electrodepositing over the dendritic deposit of (A) a metal flash comprising a major amount of a second metal other than said first metal of (A); and
(C) electrodepositing on the metal flash of (B) a dendritic metal deposit comprising a major amount of a metal other than said first metal of (A).

17. The process of claim 16 wherein the major amount of metal of step (C) is a major amount of said second metal of (B).

18. The process of either of claims 16 and 17 wherein step (B) is conducted at less than one-half the current density of step (C).

19. The process of either of claims 17 and 18 wherein step (B) comprises immersing said foil in a first aqueous bath containing a salt of said second metal, step (C) comprises immersing said foil in a second aqueous bath containing a salt of said second metal at a concentration of said second metal not more than about one-half the concentration of said second metal in the first aqueous bath of step (B).

20. The process of any one of claims 16 to 19 wherein said foil is a copper foil, said first metal is copper and said second metal is nickel.

21. The process of any one of claims 16 to 20 wherein the electrodeposition of step (B) is conducted at an average current density less than about 300 amperes per square foot.

22. The process of any one of claims 16 to 21 wherein the electrodeposition of step (B) is conducted at a average current density less than about 200 amperes per square foot.

23. The process of any one of claims 16 to 22 wherein step (B) comprises immersing said foil in an aqueous bath having a pH up to 5.0 and maintained at an elevated teperature of at least 30°C comprising at least 60 grams per liter nickel.

24. The process of any one of claims 16 to 23 wherein the major amount of metal of step (C) is nickel.

25. The process of any one of claims 16 to 24 wherein step (C) comprises immersing said foil in an aqueous bath having a pH greater than 5.0 and maintained at a temperature not greater than 30°C comprising less than 60 grams per liter nickel.

26. A process for making a copper foil comprising:
(A) obtaining a copper foil having a dendritic deposit comprising a major amount of copper on one surface of said foil;
(B) electrodepositing over the dendritic deposit of (A) a metal flash comprising a major amount of a second metal other than copper; and
(C) electrodepositing on the metal flash of (B) a dendritic metal deposit comprising a major amount of a metal other than copper.

27. The process of claim 26 wherein the major amount of metal of step (C) is the same as said second metal of step (B).

28. The process of either of claims 26 and 27 wherein said second metal is nickel.

29. The process of any one of claims 26 to 28 wherein the copper foil of (A) comprises a brass thermal barrier.

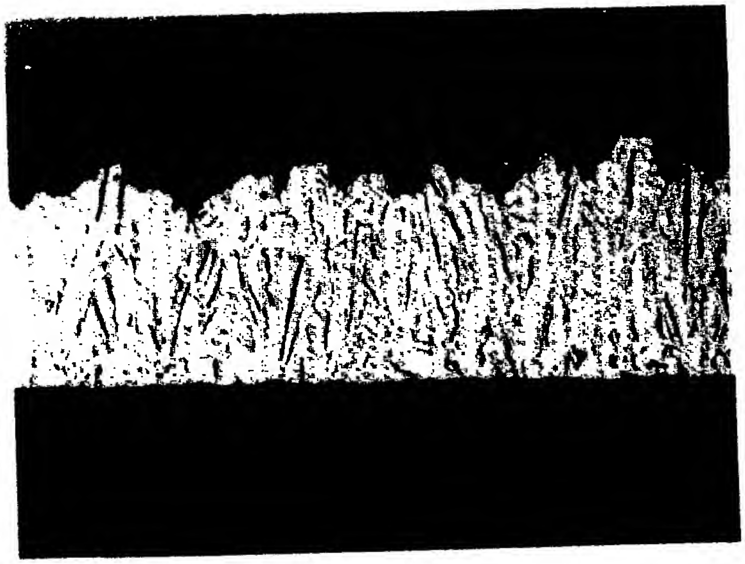

FIG. 1

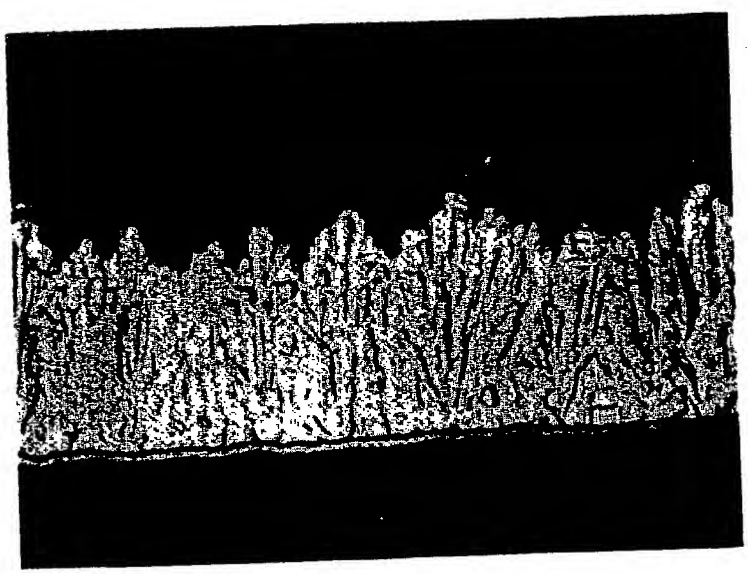

FIG. 2

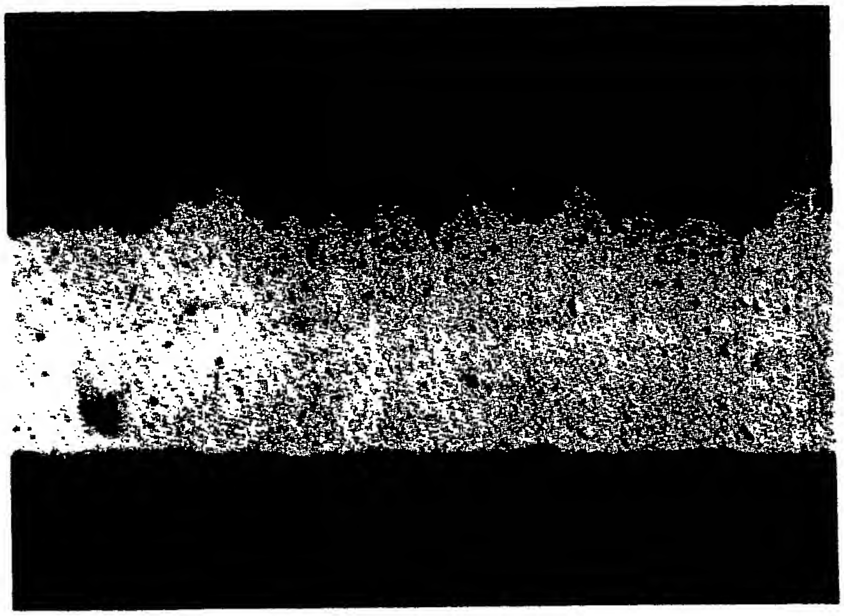

FIG. 3

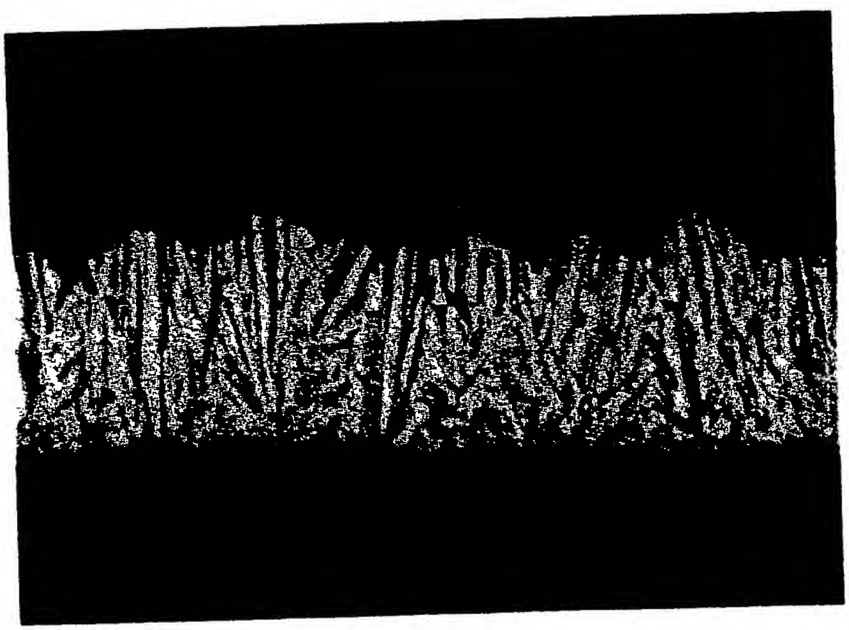

FIG. 4

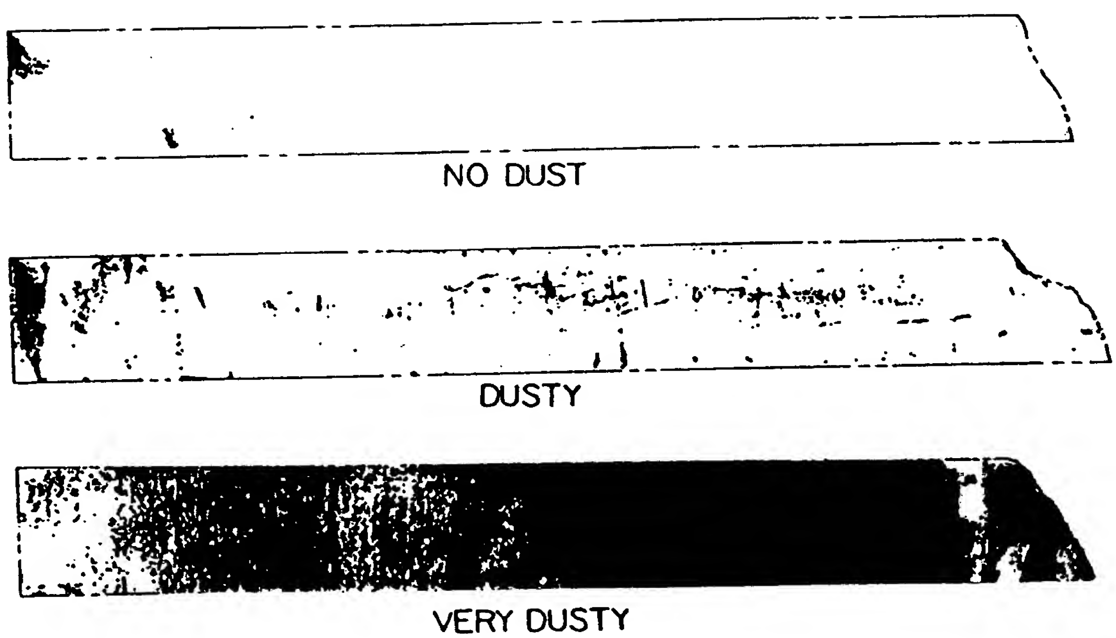

FIG. 5